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An Algorithm to Extract the Defective Areas of Potato Tubers Infected with Black Scab Disease Using Fuzzy C Means Clustering for Automatic Grading

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ABSTRACT

Estimating the surface area of defects of diseased potatoes is a key factor in the automatic grading of this product. In this article, an algorithm has been developed using fuzzy clustering method and image processing functions to estimate the defective areas of potato tubers infected with black scab disease. Fuzzy clustering, which is an unsupervised method, was used to segment color images and extract defective areas of potatoes, and image processing functions have been used to extract the total area of potatoes. In the segmentation method based on fuzzy clustering, the data matrix related to potato images were divided into separate clusters in a fuzzy way, in which the boundaries of the clusters are defined in a fuzzy way instead of being definite and specific. The results showed that this algorithm is very efficient for extracting black scab disease and can be used to extract the amount of diseases that can be used for automatic grading of this product based on the American standards.

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INTRODUCTION

Potato is one of the important agricultural products that is planted in almost all countries of the world. This food product has the fifth place in the world after wheat, rice, corn and barley. Considering the importance of this product in the food basket of the people, every effective step to increase the quality of this product in its industry and market is of special importance. Products grading is an important step to increase the quality and level of customer friendliness of products. Usually, potato grading is done manually by workers, which is time-consuming, exhausting, and costly. In the automatic grading of American standard potatoes, it is a conventional standard that has been accepted. In this standard, the detection of surface defects and the amount of defective areas is one of the key parameters in automatic grading based on quality. Therefore, the automatic classification of potatoes in machine vision systems requires that the obtained image can be optimally segmented and the area of defective areas can be extracted.

Various methods have been used to identify and extract the defects of different agricultural products, some of which are as follows. To classify the defects of Golden Delicious apples using machine vision, the pixel comparison method of the images obtained from the apples was used. In this research, each pixel of the image of an apple was compared with a model of a healthy apple that used the Mahalanobis distance method. The intended algorithm was effective in diagnosing all types of apple defects, including: bruises, roughness, skin wounds and fungus (Leemans et al., 1998). They used the Fourier expansion of the surrounding environment of apples as a method of apple classification and inspection. This method showed that the external characteristics of the product affect the human perception of quality. According to this research, if more features are included in the classification, the classification error by humans will increase (Paulus et al., 1997).

In order to separate apples with rough skin in Golden Delicious apples, the mean of the color principle (hue) was used (Heinemann et al., 1996). New methods of deep learning are also interested to the research field (Benbarrad et al., 2021).

Machine vision, backpropagation algorithm (BP) and neural networks were used to identify and classify blue tomatoes. First, three methods which included noise filtering, image segmentation and image filling were used to identify the images of blue tomatoes, then multi-layer pre-propagation artificial neural networks trained with post-propagation algorithms were used for classification. Blue tomatoes from Salem were used. The results showed that the classification accuracy is about 90% (Junlong et al., 2005). Nordam et al (2000) focused on the grading and quality inspection of high-speed potatoes and evaluated the size, shape, and external defects such as greenness, mechanical damage, and cracks. The color segmentation method used linear discriminant analysis (LDA) in combination with a Mahalanobis distance classification to classify pixels and to detect malformed potatoes using the shape classification method based on Fourier. Features such as area, central and off-central moments were used to detect similar color defects

a new inspection method to identify external defects of three potato species. Adaptive Intensity Isolation (AII) and Fixed Intensity Isolation (FII) methods were used to extract defects. Otsu's segmentation was combined with morphological operations and used to separate the skin from the background. Experiments showed that FII performed better than AII in a particular case. The rate of correct classification of defects, identification of defects, and correct inspection of potatoes based on FII was 92.1%, 91.4%, and 100%, respectively. Most of the researches that have been done in the field of potato grading in recent years have been based on size, shape and color parameters (Grenander & Manbeck, 1993; Heinemann et al., 1996; Tao et al., 1995; Tao et al., 1990; Zhou et al., 1998).

In this article, the fuzzy clustering method has been used to segment color images of potatoes with black scab disease. So that there is no need to select initial seeds (as in region-oriented segmentation methods) and image segmentation and extraction of defective areas are done unsupervised and the user has no contribution in the segmentation process. The algorithm used in this article is "Fuzzy C-Mean Clustering Algorithm" or "FCM Algorithm" in short. Another algorithm has been used to extract the total area and the area of defective areas of potatoes with black scab disease.

MATERIALS AND METHODS

For conducting experiments, ten samples of potato with black scab disease were selected and their images were taken by the machine vision system. The machine vision system used for photography is shown in Figure. 1. This system consists of a CCD camera, a lighting portfolio, a light source, two mirrors and a computer system (Chen et al., 2002; Li et al., 2002; Noordam et al., 2000).

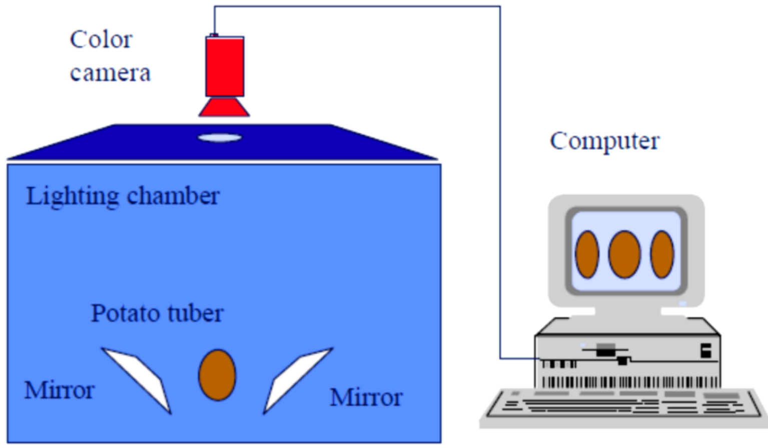

Figure 1. General structure of machine vision system

A Canon DIGITAL IXUS750 camera and a lighting bag were used for taking pictures to provide a closed environment and lighting with the same intensity, and the inner surfaces of the box were painted with white color. Different backgrounds were compared and the best images were obtained with pale blue and white backgrounds (Tao et al., 1990). Considering that the color of black dandruff disease is black, using a white background resulted in better results. A ring fluorescent lamp was installed above the product so that the light intensity was the same. In order to get the image from all directions of potato tubers, two mirrors were used to cover 360 degrees of product surfaces (Noordam et al., 2000). Ten samples of potatoes affected by black scab disease were selected and three images were obtained from each potato tuber and a total of 30 images were obtained. The obtained images were processed in a computer with specifications (Pentium (R).4, CPU 2.4GHZ, 1GB of RAM)

Algorithm outline

The algorithm for extracting the percentage of defective areas of potatoes with black scab disease, which was implemented in the Matlab image processing software, consists of two main parts (Figure. 2). The first part of the algorithm includes the segmentation (clustering) of the potato color image with the FCM clustering method. By using the FCM clustering method, the image was segmented and different parts of the image were separated with different color characteristics, and the process of extracting the patient's areas was made easier. In the second part of the algorithm, different functions of image processing, including: edge detection functions, labeling functions, area extraction functions, area descriptor functions, etc., were used to extract the total area of potato (number of healthy and defective pixels).

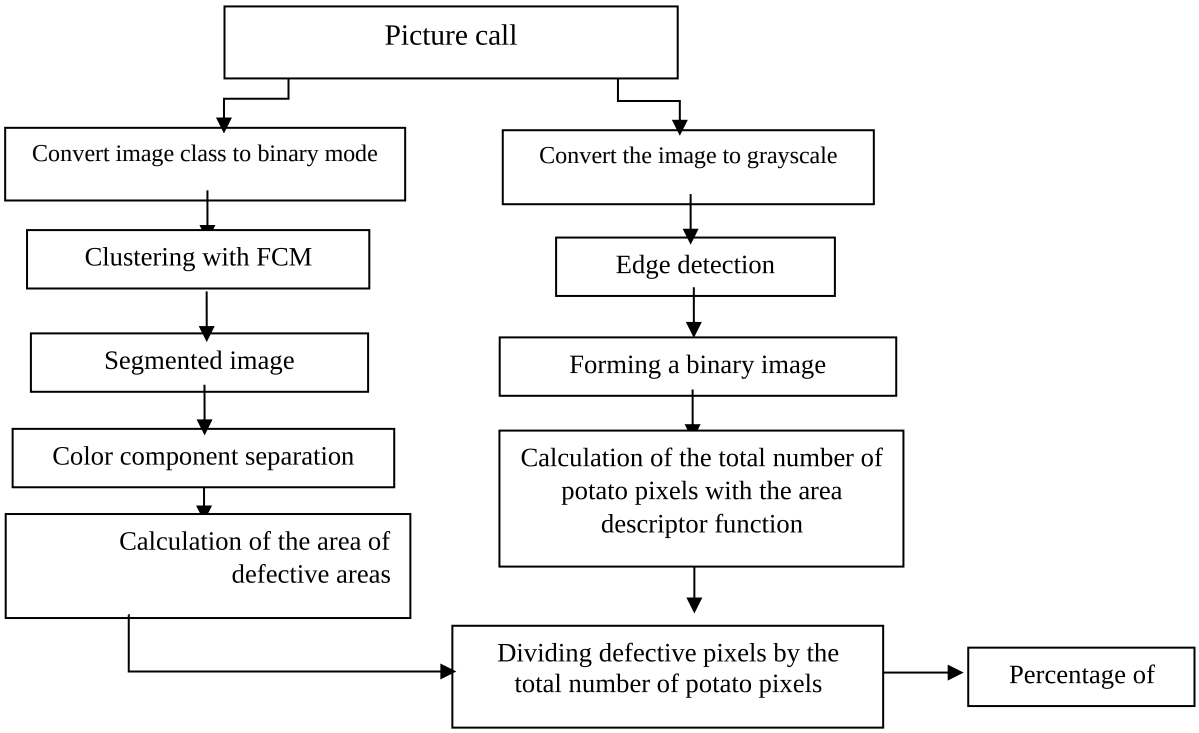

Figure 2. Algorithm for extracting defective areas

Fuzzy clustering algorithm, namely Fuzzy Mean Algorithm (FCM), was introduced by Bezdek in 1981. Clustering by fuzzy mean-c starts with an initial guess for the centers of the clusters, which aims to mark the location of the mean of each cluster. In addition, the fuzzy mean-c-algorithm allocates each data with the degree of belonging to each cluster. As the iteration process updates the cluster centers and membership degrees for each dataset, FCM iteratively moves the cluster centers to the correct location within the dataset. The repetition operation is based on the minimization of the objective function (the sum of squared errors within the group), which indicates the distance of each data or pixel to the center of the cluster (Bezdek et al., 1987; Bezdek et al., 1999; Wang, 1996).

$$J_w(U,V) = \sum_{k=1}^{n} \sum_{i=1}^{c} u_{ik}||x_k - v_i||^2 \qquad (1)$$

That:

$U=[u_{ik}]\epsilon M_c$

$V=(V_1, \dots, V_c)$

V_i is the center of cluster A_i which is defined as follows:

$$v_i = \frac{\sum_{k=1}^{n} u_{ik} x_k}{\sum_{k=1}^{n} u_{ik}} \qquad (2)$$

It is clear that V_i is the average for "C- exact clustering" (K-MEANS clustering) or the weighted average for "C- fuzzy clustering" (or FCM clustering) of all the points located in the cluster A_i. Images were segmented with FCM algorithm in RGB color space. RGB is a model that is usually used in television systems and images taken with digital cameras. Video monitors display color images by adjusting the intensity of the three primary colors. RGB is suitable for displaying color (Cheng et al., 2001; Littmann & Ritter, 1997; Pietikainen et al., 1996).

RESULT AND DISCUSSION

As explained in the materials and methods section potato samples with black scab disease were selected and photographed. Three images were obtained for each sample and a total of 30 images were obtained. The main and middle images of each sample are shown in Figure. 3.

Figure 3. Potatoes with black scab disease

The algorithm for extracting percentage of defective areas for ten potato samples was implemented in Matel software (Figure. 4). First, segmentation of images and extraction of defective areas were done with FCM clustering algorithm. To implement this algorithm, according to the color characteristics of the images, the number of clusters was selected and the images were segmented with the FCM algorithm with the number of 3 clusters, and the following results were obtained for the segmentation of the infected potato images.

The images of infected potatoes were divided into three distinct parts, the blue color of the image background, the green color of the healthy potato areas, and the red color of the defective potato areas. Considering that in FCM clustering, it is necessary to determine the number of clusters at the beginning of the operation, the desired result for clustering depends on the optimal determination of the number of clusters. In the main images of potatoes, three different colors can be seen: the background color, the color of healthy skin, and the color of defective (disease) skin. Therefore, the desired result for clustering with the number of 3 clusters was obtained. In the FCM clustering method, for better image clustering, it is necessary to have preliminary information about the color characteristics of images to determine the number of clusters, so that by determining the number of desired clusters, image segmentation can be done in a more favorable way. According to samples 3 and 5, it can be seen that the parts of the potato that do not have black scab disease are also classified as defective areas because these parts have a different color than the healthy areas and are prone to the disease. And in fact, the border of these areas is ambiguous and the fuzzy clustering algorithm has also considered these areas as defective.

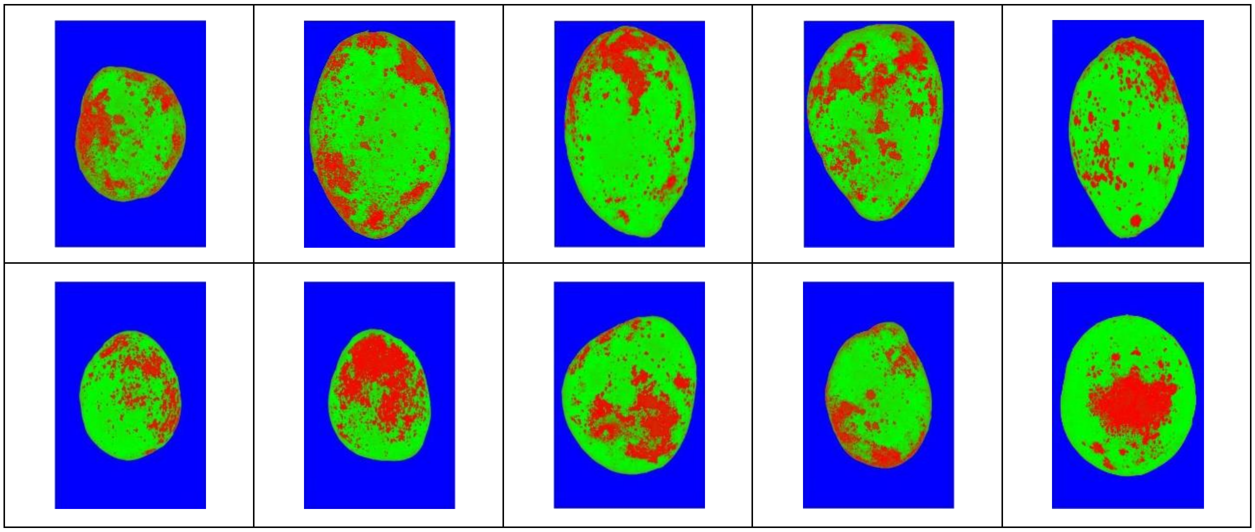

Figure 4. Clustered images of potatoes with black scab disease

After the color images of the diseased potatoes were segmented, the defective areas, which are the red color component of the segmented images, were extracted (Figure. 5). According to these images, the number of pixels of defective areas were extracted (Table 1).

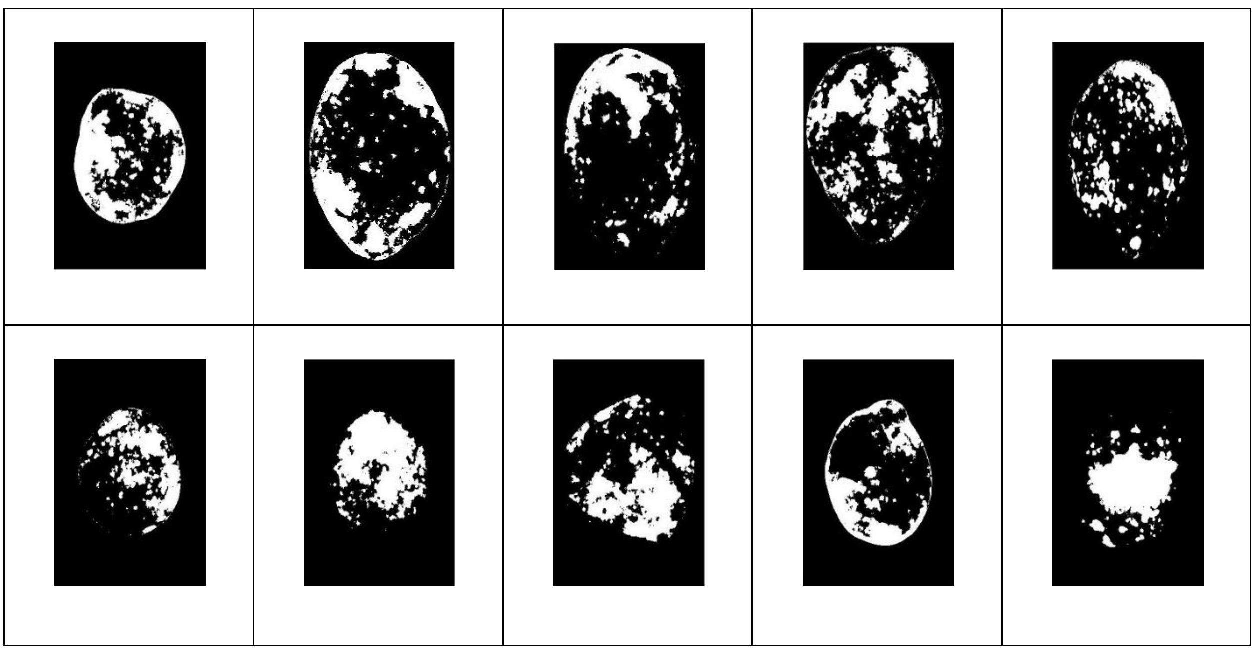

Figure 5. Defective areas of infected potatoes

The second part of the algorithm for extracting the percentage of defective areas was implemented to extract the total area of potato (the area obtained from three images for each sample). To extract the total area, using image processing functions, edge images were found and separated from the background then all the internal parts of the image were removed and only the border of the image areas was obtained, which can be seen in Figure. 6.

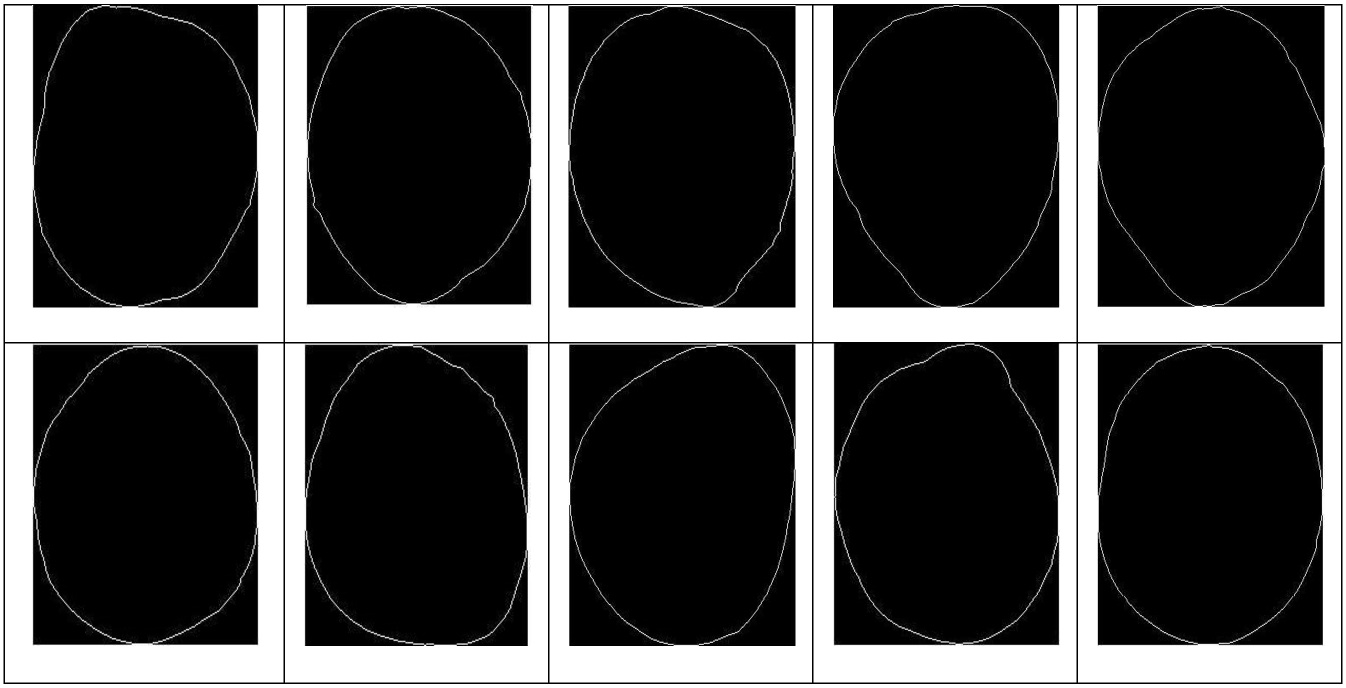

Figure 6. The border of potatoes to extract the total area of potatoes

Due to the fact that the thickness of the border of the region is one pixel, for better viewing, the images are shown with a larger size. After extracting the boundaries of the regions, the total area of potato was obtained by dividing the area (number of pixels) of defective areas by the area (number of pixels) of the whole potato, the percentage of defective areas of potatoes with black scab disease was obtained (Table 1).

Table 1. Area (number of pixels) of defective areas of potatoes with black scab disease

Samples	1	2	3	4	5	6	7	8	9	10
Area of defective areas	44214	52878	31475	32801	36771	33532	25253	50331	38107	20844
The total area of potatoes	166140	140910	106564	103069	84174	120921	82361	120418	73387	70636
Percentage of defective areas	0/26	0/37	0/29	0/31	0/43	0/27	0/30	0/41	0/52	0/29

CONCLUSION

In this article, an algorithm for extracting the percentage of defective areas of potatoes with black scab disease was designed and implemented in the software. In this algorithm, the FCM clustering method was successfully used to segment the color images of potatoes with black scab disease and different image processing functions were used to extract the total area of the potato. Among the advantages of this algorithm is that image segmentation and extraction of the percentage of defective areas in it is done unsupervised and it can be used in the automatic grading of potatoes based on the American standard. Also, in image segmentation, fuzzy logic has been used, and the areas that are susceptible to disease and have the same color as the defective areas are also segmented as diseased areas, which can be used to isolate suspicious potatoes.

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